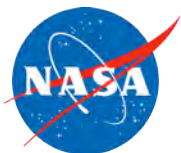


625-20-004

Project completion

# Numerical Simulations for Active Tectonic Processes

PI: Andrea Donnellan, JPL

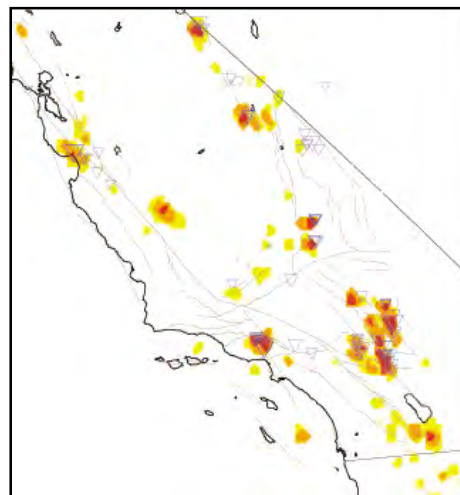


# Numerical Simulations for Active Tectonic Processes

PI: Andrea Donnellan, JPL

## Objective

- Design and construct a web portal based framework that integrates earthquakes models with observational data for study of seismic events
- Realistic modeling of Earth crustal fault interactions based on observational data.



*Pattern recognition techniques show promise for earthquake forecasting. Red regions indicate anomalies detected through principal component analysis. Blue triangles are earthquakes. Recent earthquakes have occurred in anomalous regions.*

## Approach

- Parallelize existing earthquake modeling codes to enable higher resolution
- Design and implement a web-based portal for running modeling codes and accessing seismic databases
- Re-engineer model implementations for scalability and performance
- Integrate model output with observations to allow major improvement in prediction fidelity

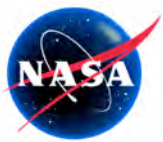
## CoIs:

John Rundle, University of California at Davis,  
Geoffrey Fox, Indiana University,  
Dennis McLeod, University of Southern California

## Key Milestones

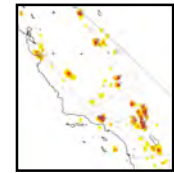
- Come to agreement on design policy for interoperability and community delivery 7/02
- Interoperability prototype tested with improved codes (Virtual California and GeoFEST) 2/03
- 100X modeling resolution improvement 6/03
- Integration of 12 codes into the framework 2/04
- Additional 30X resolution improvement 6/04
- All software published via the WWW. Issue testable 5 year earthquake forecast for S.California 9/04

TRL<sub>in</sub> = 4



# Donnellan, Numerical Simulations for Active Tectonic Processes

<http://quakesim.jpl.nasa.gov/>



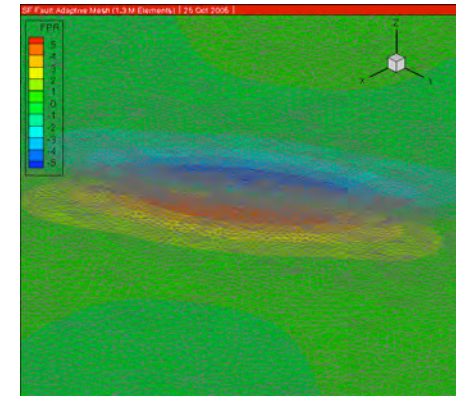
625-20-004

PI: Andrea Donnellan, JPL

## Objective

- Design and construct a web portal based framework that integrates earthquakes models with observational data for study of seismic events
- Realistic modeling of Earth crustal fault interactions based on observational data.

*Visualization of the finite element mesh of the San Andreas fault model with fault parallel rates.*



## Accomplishments

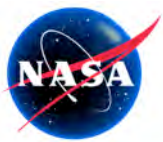
*QuakeSim is a fully interoperable system for studying active tectonics and earthquakes.*

- Developed simulation and analysis tools to study the physics of earthquakes using state-of-the-art modeling, data manipulation, and pattern recognition technologies and developed clearly defined accessible data formats and code protocols as inputs to the simulations
- Completed delivery of a web-services problem-solving environment that links together diverse earthquake science applications on distributed computers
- Portal integration and use of the Pattern Informatics (PI) code has successfully been used to forecast California seismic hotspot activity with an 11 km resolution (at project close, of the most recent 18 "significant" earthquakes in California, 16 occurred within the forecast hotspots)
- Completed the high end computing implementation of three major simulation tools: PARK, GeoFEST and Virtual California and then delivered the QuakeSim portal system to our customers with 13 incorporated applications.
- PARK, GeoFEST and Virtual California met or exceeded their code improvement goals
- GeoFEST has been downloaded by more than 80 customers
- 53 peer-reviewed publications and 29 other articles, abstracts and posters
- 7 New Technology Reports and 4 NASA Space Act Awards

TRL=4<sub>in</sub>-6<sub>out</sub>

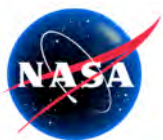
Computational Technologies

**ESTO**  
Earth-Sun System Technology Office



625-20-004

# Achievement Quads



# Donnellan, Numerical Simulations for Active Tectonic Processes

<http://quakesim.jpl.nasa.gov/>



625-20-004

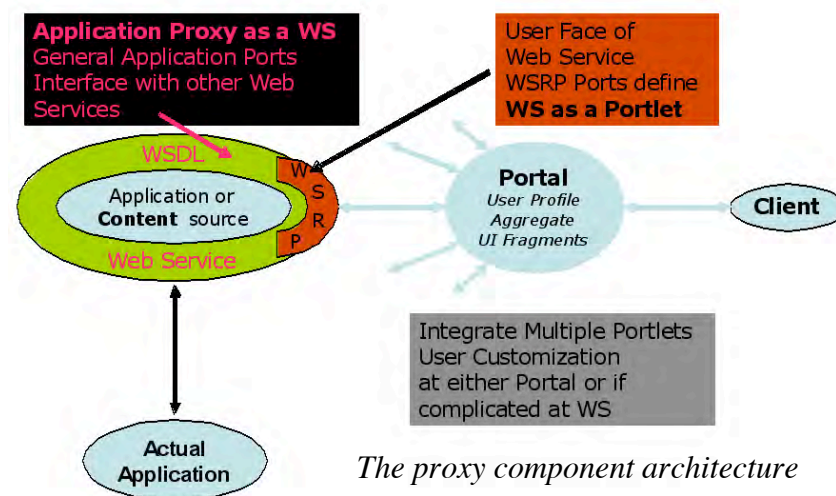
PI: Andrea Donnellan, JPL

## Description

- Design and construct a web portal based framework that integrates earthquakes models with observational data for study of seismic events

## Objective

- Realistic modeling of Earth crustal fault interactions based on observational data.



## Accomplishments

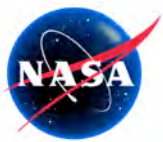
- Appointed Science Review Board
- Developed and posted project requirements.
- Documented and posted benchmark codes.
- Chose an integrated web-services based environment using proxy component architecture.
- Chose Open Channel Foundation to post s/w.
- Developed/posted core service definitions in Web Services Definition Language (WSDL).
- Prototyped module *disloc* in the framework and ran it as a web service.

## Key Milestones (11 milestones total)

- H - Come to agreement on design policy for interoperability and community delivery 7/02 (12/02)
- I - Interoperability prototype tested with improved codes (Virtual California and GeoFEST) 2/03
- F - 100X modeling resolution improvement 6/03
- J - Integration of 12 codes into the framework 2/04
- G - Additional 30X resolution improvement 6/04
- K - All software published via the WWW. Issue testable 5 year earthquake forecast for S. California 9/04

TRL=4<sub>in</sub> - 4<sub>current</sub>





# Donnellan, Numerical Simulations for Active Tectonic Processes

<http://quakesim.jpl.nasa.gov/>



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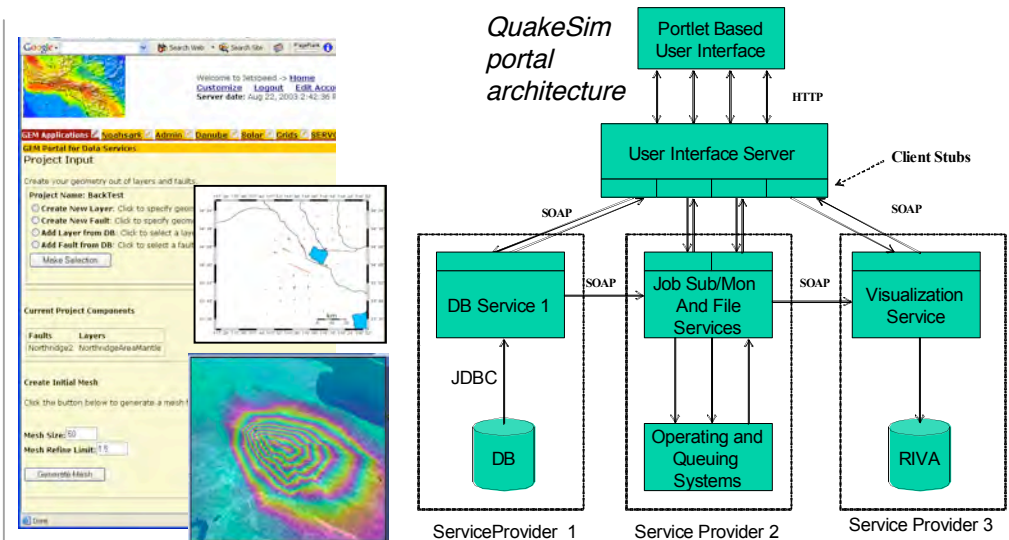
PI: Andrea Donnellan, JPL

## Description

- Design and construct a web portal based framework that integrates earthquakes models with observational data for study of seismic events

## Objective

- Realistic modeling of Earth crustal fault interactions based on observational data.



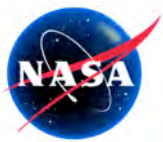
## Accomplishments

- Developed prototype of integrated portal system, using the QuakeSim Problem Solving Environment, to connect mesh generation, finite element solver codes, databases, and visualization services.
- Developed XML-based common data formats and corresponding Web services to allow selected codes to share information.
- Demonstrated code interoperability in a web services environment.
- Posted supporting documents.

## Key Milestones (11 milestones total)

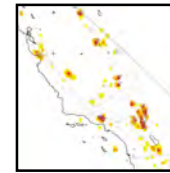
- H - Come to agreement on design policy for interoperability and community delivery 7/02 (12/02)
- I - Interoperability prototype tested with improved codes (Virtual California and GeoFEST) 2/03 (7/03)
- F - 100X modeling resolution improvement 6/03
- J - Integration of 12 codes into the framework 2/04
- G - Additional 30X resolution improvement 6/04
- K - All software published via the WWW. Issue testable 5 year earthquake forecast for S. California 9/04

TRL=4<sub>in</sub> - 5<sub>current</sub>



# Donnellan, Numerical Simulations for Active Tectonic Processes

<http://quakesim.jpl.nasa.gov/>



625-20-004

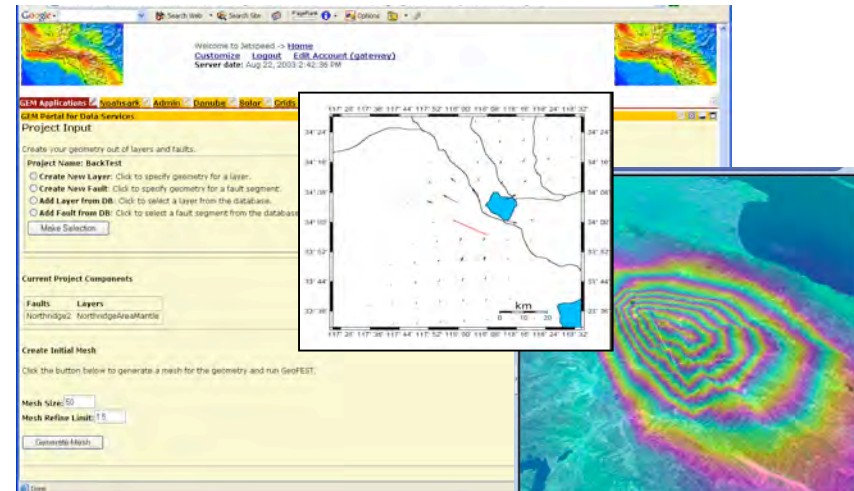
PI: Andrea Donnellan, JPL

## Description

- Design and construct a web portal based framework that integrates earthquakes models with observational data for study of seismic events

## Objective

- Realistic modeling of Earth crustal fault interactions based on observational data.



## Accomplishments

- PARK Code (Multipole boundary element code for simulating the Parkfield region of the San Andreas Fault) - runs 10X elements with 10X time resolution in same time to solution
- GeoFEST Code (Finite element code for simulating viscoelastic deformation) - runs 25X elements @ 5X throughput on Landers earthquake event simulation
- Source code available to science community via the WWW

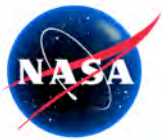
## Key Milestones (11 milestones total)

H - Come to agreement on design policy for interoperability and community delivery	7/02 (12/02)
I - Interoperability prototype tested with improved codes (GeoFEST)	2/03 (7/03)
F - 100X modeling resolution improvement	6/03 (1/04)
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## Projected Infusion

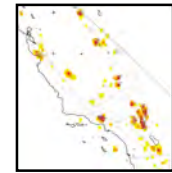
*Southern California Integrated GPS Network, Earth-Scope, future InSAR mission, USGS hazard maps*

TRL=4<sub>in</sub>-5<sub>current</sub>



# Donnellan, Numerical Simulations for Active Tectonic Processes

<http://quakesim.jpl.nasa.gov/>



625-20-004

PI: Andrea Donnellan, JPL

## Description

- Design and construct a web portal based framework that integrates earthquakes models with observational data for study of seismic events

## Objective

- Realistic modeling of Earth crustal fault interactions based on observational data.

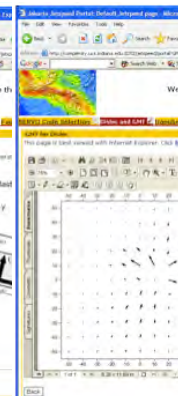
QuakeSim  
entry page



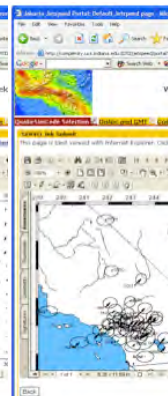
Fault geometry  
specification



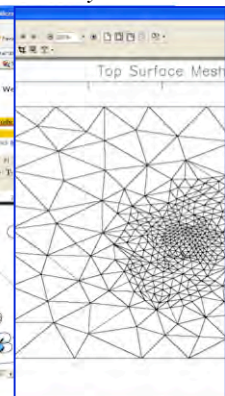
Disloc surface  
vectors



Geofit  
output



Adaptive mesh  
used by GeoFEST



## Accomplishments

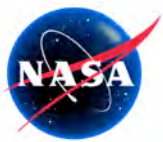
- Integrated 12 geophysical applications into the QuakeSim Problem Solving Environment: Disloc, Simplex/Geofit, GeoFEST, VirtualCalifornia, Mesh Generation, SLIDER, Phase Dynamical Probability, Karhunen-Loeve Space-Time Pattern Analysis, Genetic Algorithm Analysis codes, and Hidden Markov Model Codes.
- Updated QuakeSim Portal documents: Installation Guide, User's Guide, User Validation document, Software Test Plan, and Requirement Traceability Matrix.
- Generalized the fault database.
- Demonstrated GeoFEST with adaptive meshing.

## Key Milestones (11 milestones total)

- |   |              |
|---|--------------|
| H - Come to agreement on design policy for interoperability and community delivery                  | 7/02 (12/02) |
| I - Interoperability prototype tested with improved codes (GeoFEST)                                 | 2/03 (7/03)  |
| F - 100X modeling resolution improvement  | 6/03 (1/04)  |
| J - Integration of 12 codes into the framework  | 2/04 (7/04)  |
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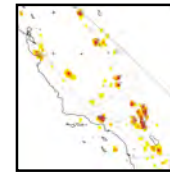
TRL=4<sub>in</sub>-5<sub>current</sub>





# Donnellan, Numerical Simulations for Active Tectonic Processes

<http://quakesim.jpl.nasa.gov/>



625-20-004

PI: Andrea Donnellan, JPL

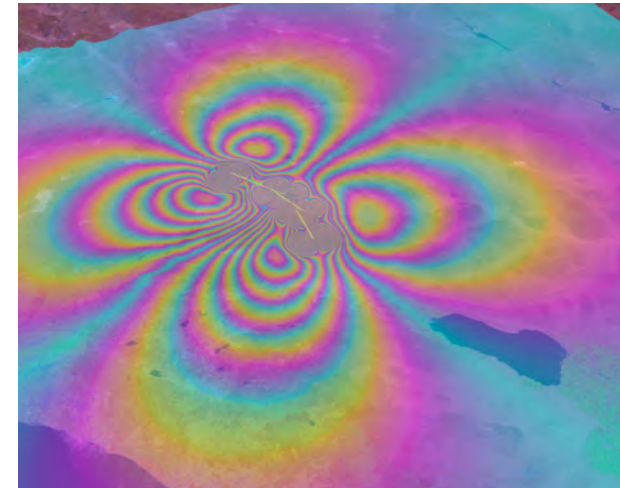
## Description

- Design and construct a web portal based framework that integrates earthquakes models with observational data for study of seismic events

## Objective

- Realistic modeling of Earth crustal fault interactions based on observational data.

*GeoFEST  
simulated  
surface  
displacement  
from coseismic  
Landers model,  
displayed as  
InSAR fringes*



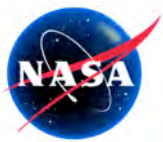
## Accomplishments

- Exceeded all three code improvement requirements:
- PARK on 1024 CPU machine with 400,000 elements, 50,000 time steps in 5 times the baseline code
  - GeoFEST: 16M elements, 1000 time steps in the same time as the baseline code using the PYRAMID AMR libraries
  - Virtual California with N=700 segments for 10,000 time steps in 1 hour or less, MPI parallel implementation, running on M-processor machine, with 2 GB of memory per CPU, speedup of approximately M/2 on up to 256 processors.

## Key Milestones (11 milestones total)

- |   |              |
|---|--------------|
| H - Come to agreement on design policy for interoperability and community delivery                  | 7/02 (12/02) |
| I - Interoperability prototype tested with improved codes (GeoFEST)                                 | 2/03 (7/03)  |
| F - 100X modeling resolution improvement  | 6/03 (1/04)  |
| J - Integration of 12 codes into the framework  | 2/04 (7/04)  |
| G - Additional 30X resolution improvement   | 6/04 (8/05)  |
| K - All software published via the WWW. Issue testable 5 year earthquake forecast for S. California | 9/04         |

TRL=4<sub>in</sub>-6<sub>current</sub>



# Donnellan, Numerical Simulations for Active Tectonic Processes

<http://quakesim.jpl.nasa.gov/>



625-20-004

PI: Andrea Donnellan, JPL

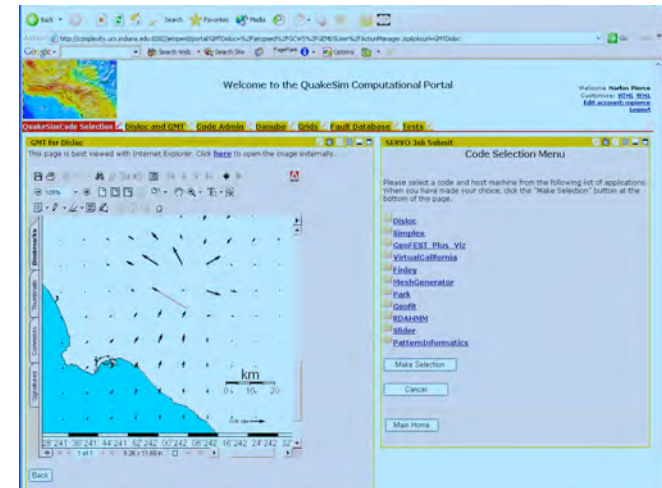
## Description

- Design and construct a web portal based framework that integrates earthquakes models with observational data for study of seismic events

## Objective

- Realistic modeling of Earth crustal fault interactions based on observational data.

*The QuakeSim portal is based on portlet components*



## Accomplishments

- Demonstrated the integration of an external user application into the framework using the GRID framework wizards
- Issued a testable 5 year earthquake forecast for  $M > 5$  for S California and published the availability of the Portal to the Earthquake community in the peer-reviewed periodical *Computing in Science and Engineering*

## Key Milestones (11 milestones total)

- |   |              |
|---|--------------|
| H - Come to agreement on design policy for interoperability and community delivery                  | 7/02 (12/02) |
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TRL=4<sub>in</sub>-6<sub>current</sub>